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DT/RSPA/MTB-78/2

HAZARD CLASSIFICATION OF EXPLOSIVES FOR TRANSPORTATION—NONSOLID EXPLOSIVES (Phase III)

CHARLES B. DALE

AUGUST 1978

FINAL REPORT

Document is available to the U.S. public through
the National Technical Information Service,
Springfield, Virginia 22161.

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
Materials Transportation Bureau
Washington, D.C. 20590

Technical Report Documentation Page

1. Report No. DOT/RSPA/MTB-78/2	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle HAZARD CLASSIFICATION OF EXPLOSIVES FOR TRANSPORTATION–NONSOLID EXPLOSIVES (PHASE III)		5. Report Date August 1978
		6. Performing Organization Code NAVORDSTA, Indian Head,5251A
7. Author(s) C. B. Dale		8. Performing Organization Report No.
9. Performing Organization Name and Address Naval Ordnance Station Indian Head, Maryland 20640		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DOT-AS-30043
12. Sponsoring Agency Name and Address U.S. Department of Transportation Research and Special Programs Administration Materials Transportation Bureau Washington, D.C. 20590		13. Type of Report and Period Covered Final Mar 73-Mar 76
		14. Sponsoring Agency Code DMT-1
15. Supplementary Notes		

16. Abstract

Explosive sensitivities, major field tests, and some accidents in transportation were compiled for selected monopropellants, slurry explosives, and blasting agents. To supplement information in the literature, the projectile impact, card gap, and General Electric input-output sensitivities of certain slurry explosives and blasting agents were measured. It was concluded that the projectile impact, the card gap, and the cap test results all depend on the method of conducting of the test to such an extent that the explosive classification in some cases can be changed from UN 1.1 to 1.3. A scheme for explosive hazard classification based on the new United Nations systems is discussed.

17. Key Words Liquid monopropellants, Water gels, Blasting agents, Hazard classification, Hazardous materials, Transportation		18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 30	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGEMENT

Valuable discussions held with personnel of the U.S. Bureau of Mines, Safety Research Center, Pittsburgh, PA, and with personnel of General Electric Co., NASA Mississippi Test Facility, Bay St. Louis, MI, are gratefully acknowledged. The following persons participated in the testing and contributed improvements to the test methods: A. J. Bannister and T. W. Woodland; J. Frigiola conducted the General Electric input-output tests and coordinated the fragment impact tests which were performed by the H. P. White Co., Bel Air, MD. Mr. E. E. Harton, Jr. was the contract monitor for the Department of Transportation

METRIC CONVERSION FACTORS

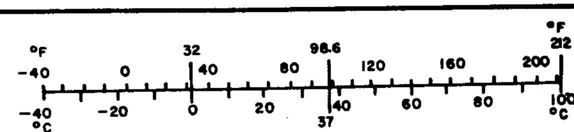
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SUMMARY

Purpose:

This report reviews the explosive sensitivity data of monopropellants and water gel explosives in the literature. It also records experimental data obtained in order to fill some of the gaps in the existing data. The purpose of the report was to apply the data to formulating an explosive classification scheme.

Results:

Sensitivity data on present-day liquid monopropellants indicate that, in spite of being listed as non-explosives, the propellants are potential explosive hazards.

Data on water gel explosives show that the Naval Ordnance Laboratory, White Oak, card gap data range from zero to over seventy cards. The unconfined critical diameters range from greater than 1 inch to less than 3 inches. Review of the fragment impact data appear to show a correlation between the severity of the reaction and the data of the card gap test. The General Electric input-output test was negative for all materials tested. Consideration of the cap test, card gap test and projectile impact test shows that the classification of explosives can be changed depending on the method of conducting the tests.

Recommendations:

It is recommended that the cap test be accepted at this time to distinguish between class A explosives and blasting agents. As a result, it is also recommended that the explosive classification scheme should not include the card gap test.

INTRODUCTION

The classification of explosives for transportation and storage at the present time is based on two documents: (1) the Code of Federal Regulations Title 49, Parts 100 to 199[1] and (2) the military hazard classification procedures known as Navy Instructions 8020.3.[2] The present edition of CFR 49 requires a very limited number of evaluation tests, such as

(1) The blasting cap test

(2) The impact (or drop weight) test

(3) The thermal stability test

(4) A variety of bonfire tests.

Both liquids and solids can be and are evaluated by the methods listed above. The military classification requirements include these tests but, in addition, call for other detonation tests. Additional detonation tests are the NOL card gap test and the use of a 30-gram tetryl pellet in the case of a rocket motor.

Considerable discussion over the years has centered on the validity and applicability of the tests in relation to the actual transportation environment to which the hazardous chemical is exposed. It is precisely this aspect of the classification procedures which is difficult to resolve. In particular, conditions under which monopropellants and slurry explosives are handled and exposed appear to require further study. In the case of the monopropellant, a substantial contribution was made by the Liquid Propellant Information Agency (LPIA) in the publication of liquid propellant test methods,[3] mainly in the period 1959-1960.

In the present study the objective is threefold:

(1) Survey existing hazard evaluation data

(2) Obtain new test data

(3) Recommend changes in the hazard classification procedures as they affect liquids, slurry explosives, and blasting agents.

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[1]Code of Federal Regulations Title 49, Transportation, Parts 100 to 199, Revised as of 1 October 1976, published by the Office of the Federal Register.

[2]Department of the Navy, Washington, D.C., NAVORDINST 8020.3, Explosives Hazard Classification Procedures, 19 May 1967.

[3]Liquid Propellant Information Agency, Applied Physics Laboratory, Johns Hopkins University, Laurel, Md., "Liquid Propellant Test Methods" (no date: 1960's).

LITERATURE SURVEY

In order to develop and improve explosive hazard classification methods, a review of existing hazard data of energetic materials is necessary as a starting point. A brief survey has been made of monopropellants and slurry explosives. The properties of primary interest are those which give a measure of the reactivity to impact/shock or thermal effects.

Monopropellants:

A listing of the explosive and flammability sensitivity test results for four monopropellants—monomethyl hydrazine (MMH), 90% hydrogen peroxide (H_2O_2), nitromethane, and monopropellant GMP No. 2—and for one reactive chemical—ethylene oxide—is given in Table I.

TABLE I. ENERGETIC LIQUIDS

Test	MMH	90% H_2O_2	Nitromethane	Ethylene oxide	Monopropellant 2
1 Adiabatic compression (psi)		2000 (air)	850 (N_2)[1]		200
2 Cavity drop (cm)			>100		19
3 Blasting cap	Negative	Negative at 25°C Positive at 60°C	Partial[1] (#6 cap)	Negative	Negative
4 Critical diameter (in)		>1.05, <1.25[2] >0.82, <1.05[3]	<1		1.4
5 Detonation propagation		Positive	Positive		Positive
6 Card gap (cards)	Negative	0 (25°C) 11 (50°C)	18-20[1,4]	Negative	>0, <1[4,5] >12, <15[5,6]
7 Bullet impact	Negative	Negative	Partial[7,8]	Negative	1+/7[9]
8 High velocity fragment			Positive		Negative
9 Bonfire	Vapors explode		Vapors ignite	Vapors explode	Vapors ignite
10 Bag igniter in drum					No ignition
11 Vapor ignition	Explosive		Burning	Explosive	Ignition above 298°F
12 DOT classification	Flammable liquid	Corrosive liquid	Flammable liquid	Flammable liquid	NOIBN
13 NFPA classification	Potential explosive	Potential explosive	Potential explosive	Potential explosive	Potential explosive

[1] National Board of Fire Underwriters, New York, N.Y., Nitroparaffins and Their Hazards, Research Report 12, 1959.
[2] Aluminum; 25°C.
[3] Aluminum; 50°C.
[4] 1-Inch diameter.
[5] Ambient temperature.
[6] 1.44-Inch diameter.
[7] Partial reaction signifies an explosion but not a detonation.
[8] 0.50-Caliber.
[9] One positive; seven trials.

Of the monopropellants, the hydrogen peroxide, nitromethane, and GMP No. 2 can all be made to detonate in the liquid phase. Methylhydrazine and ethylene oxide cannot be initiated in the liquid phase. The distinction in sensitivity between the monopropellants may be based on the card gap test, the critical diameter, and the flammability of the vapor. None of the monopropellants are classed as class B explosives. However, precautions are taken with the ones that are detonable in the liquid phase by packaging them in drums rather than in tank cars. Additional restrictions may be imposed in the storage of monopropellants; e.g., quantity-distance limitations. It is clear, therefore, that, while the detonable liquids do not meet the requirements of class B propellants, they are nevertheless potential detonation hazards and must be treated as such. One of the main criteria for establishing the detonability of a liquid is that it can be detonated in 1-inch-diameter metal tubing.[4] Since none of the liquids listed here, except nitromethane, meet that requirement, they fall automatically into a nonexplosive class.

At the present time the adiabatic compression test[5] and the cavity drop test[4] serve only as broad guides in assessing the ease of initiation of liquid propellants. No attempt has been made by any one to establish criteria for class A or class B liquid explosives based on either the adiabatic compression test or the cavity drop test. No mention has been made here of the compatibility of any of the liquid propellants with either the container, gasket material, lubricants, or overpacking. It should be noted that an insensitive liquid can be sensitized by impurities.

Slurry Explosives:

The results from the explosive and flammability sensitivity tests of six slurry explosives are given in Table II. Three of the explosives are listed as class B explosives. Slurry explosives consist basically of a water solution of ammonium nitrate, other inorganic oxidizers, and gum. The addition of aluminum, explosive sensitizers, and small air bubbles can lead to placing slurry explosives in class A. In accordance with established military procedures for the classification of explosives, the card gap test is a requirement. The critical diameter for class A explosives has to be less than 1.44 inches. For most class B slurry explosives it can be expected that the critical diameter will be greater than 1.5 inches. For example, GSX-4 has a critical diameter which is slightly above 1.5 inches. When combined with a card cap value of 44, GSX-4 appears to have explosive properties close to those of a class A explosive. On the other hand, GSX-3 is relatively insensitive to explosive shock.

Other tests which are indicators of the ease of initiation are the minimum booster test and the projectile impact[6] test. The minimum booster test is closely related to the card gap test and it would be expected that the values for one test follow the order of the values for the other test. The booster test is run with 50-50 pentolite boosters of 15 and 27 grams placed in contact with the explosive contained in 2- or 3-inch-diameter nonmetallic tubes.

[4] Liquid Propellant Information Agency, Applied Physics Laboratory, Johns Hopkins University, Laurel, Md., "Liquid Propellant Test Methods" (no date: 1960's).

[5] National Board of Fire Underwriters, 85 John St., New York, N.Y. 10038, Nitroparaffins and Their Hazards, Research Report 12, 1959.

[6] Department of the Interior, Washington, D.C., "Methods of Evaluating Explosives and Hazardous Materials," Bureau of Mines Circular 8541, 1972.

TABLE II. WATER GEL BLASTING AGENTS

Test	GSX-3	GSX-4	GSX-5	GSX-6	GSX-1	GSX-2
1 Impact	Negative	Negative	Negative	Negative		
2 Cavity drop	Negative	Negative	Negative	Marginal		
3 Friction	Negative	Negative	Negative	Positive		
4 Electrostatic discharge	Negative	Negative	Negative	Positive		
5 Blasting cap	Negative	Negative	Negative	Positive	Positive	Positive
6 Bullet impact	Negative	Negative	Negative	Positive	Negative	Negative
7a Card gap (NOL) (cards)	0	44	15	>70	>0	Partial at 0
7b Card gap (2-in dia) (cards)	0	Partial at 0				
8 Critical diameter (in) (unconfined)	>2, <3	>1.5, <2	>1, <1.5	<2.0		
9 Min. booster, pentolite (g) (2-in dia)	15[1]	27	18	13		
10 Input-output (GE test)	Negative	Negative			Negative	Negative
11 Flying fragment	1/1[2], 0/1[3]	1/1[2], 1/1[3]			Positive[4]	Positive
12 Aluminum	None	None	Yes	Yes	None	None
13 TNT	None	None	None	None	None	None
14 Explosive sensitizer	Yes	Yes	None	None	Yes	Yes
15 Explosive classification	B	B	B	A	A	A

[1] 3-Inch diameter.
[2] Aluminum container, mild reaction when positive.
[3] Cardboard container, mild reaction when positive.
[4] Metal pipe, major reaction.

Slurry explosives GSX-3, GSX-5, and GSX-6 appear to follow this general rule, taking into account that the minimum booster for GSX-3 would be much larger (possibly infinite) if the test sample diameter had been 2 inches.

The flying fragment test (test No. 11, Table II) indicates the degree of reactivity of the various slurry explosives. Slurry explosives GSX-3 and GSX-4 yielded mild explosive reactions while GSX-1 and GSX-2 gave major reactions, again confirming the findings based on the card gap, blasting cap, and critical diameter tests.

REVIEW OF ACCIDENTS AND MAJOR FIELD TESTS

Information obtained from accident investigations and large-scale tests can provide an important source of information to support the validity of scaling up laboratory test results.

An evaluation of the detonation hazard with slurry explosives and blasting agents caused by a fire was made on a large scale in 1973 in Canada.[7] In each of three bonfire tests, a truck was loaded with 10,000 pounds of water gels or ANFO* as shown in Table III. In all three tests, no explosion took place. As a result of these tests, the Canadian Government has permitted truck transportation of 40,000 pounds of slurry explosives or ANFO. No accidents have been reported as a consequence of the new regulations.

[7] Department of Energy, Mines and Resources, Ottawa, Canada, Burning Trials of Blasting Agents, by J. A. Darling, Internal Report 73/152, December 1973.

*Ammonium nitrate - fuel oil.

TABLE III. WATER GEL AND ANFO BONFIRE TESTS

Test No.	Material	Quantity (lb)	Classification	Result
1	Sensitized explosive, class B	10,000	B	No explosion
2	Slurry Explosives w/Al	10,000	A	No explosion
3	ANFO	10,000	NCN	No explosion

Data for monopropellants are given in Table IV. Of the cases listed in Table IV, the railroad car which eventually detonated was exposed to the impact of other railroad cars during a switching operation. Subsequently, a series of tests was conducted with drums of nitromethane. No comparable data were reported in the case of methylamine-nitrate.[8] Detonations were obtained with drums of nitromethane when subjected to impact by a 0.50-caliber bullet and by a 5-pound plate traveling at 8100 ft/s.

TABLE IV. MONOPROPELLANT ACCIDENTS

Material	Date	Location	Quantity
Nitromethane[1]	22 Jan 1958	Niagara Falls, N.Y.	77,380 lb
Nitromethane[1]	1 Jun 1958	Mt. Pulaski, Ill.	1 railroad tank car
Methylamine nitrate[2]	6 Aug 1974	Wenatchee, Wash.	10,000 gal

[1]National Board of Underwriters, New York, N.Y., Nitroparaffins and Their Hazards, Research Report 12, 1959.
[2]National Transportation Safety Board, Washington, D.C., Burlington Northern, Inc., Monomethylamine Nitrate Explosion, Wenatchee, Wash., Railroad Accident Report NTSB-RAR-76-1, August 6, 1974.

While no data were reported, enough information was apparently available for the National Transportation Safety Board to conclude that cavitation could have been a cause to detonate monomethylamine nitrate. Therefore, it can be concluded that, for both liquids, the possibility exists that cavitation and sensitization caused by impurities can cause explosive reactions.

[8]National Transportation Safety Board, Washington, D.C. 20594, Burlington Northern, Inc., Monomethylamine Nitrate Explosion, Wenatchee, Wash., Railroad Accident Report No. NTSB-RAR-76-1, August 6, 1974.

EXPERIMENTAL

The literature survey was supplemented with experimental work in three areas:

(1) Modified card gap test

(2) General Electric Co., "Input-Output Energy" test (vented bomb test)

(3) Fragment impact test.

Modified Card Gap:

The card gap test is an initiation sensitivity test using an explosive booster. The test normally determines the number of cellulose acetate cards which just prevent initiation of a detonation in the explosive sample. A well-known version of the card gap test was developed by the Naval Ordnance Laboratory (now known as NSWC, White Oak). The NOL version, which is described in NAVORDINST 8020.3,[9] uses heavy wall steel tubing with an internal diameter of 1.44 inches and an outside diameter of 1.875 inches. The present, modified version uses somewhat less confinement and a larger internal diameter by employing plexiglass* tubing with a 2-inch internal diameter and a 1/8-inch wall thickness.

The reason for the 2-inch internal diameter is to accommodate explosives with critical diameters up to 2 inches. The choice of a 2-inch internal diameter is based on the fact that some water gel type of explosives have a critical diameter close to 1-1/2 inches and, therefore, might not detonate in the NOL card gap test. The test equipment is shown in Figure 1.

GE Input-Output Energy Test:

The General Electric Co. input-output energy test can also be described as a vented bomb test. It is used for testing samples of explosives and combustible materials to determine whether they can generate any significant gas pressure when subjected to a standard ignition input. Electric pyrotechnic devices, such as electric matches or flash vented squibs, are used to provide the ignition for the test sample.

The vented bomb (Figures 2 and 3) consists of an 18-inch section of 3-inch double extra strength (XXS) steel pipe with forged steel end caps. The interior volume of the bomb is approximately 80 cubic inches. One end cap has been drilled to allow gas to gain access to a fixture holding a rupture disc. The rupture disc specified by GE is made of aluminum foil sandwiched between two layers of paper. It ruptures at about 30 psig. The other end cap was modified by drilling a 3/32-inch-diameter hole through the center. The ignition device lead wires were passed through this hole when the closed bomb was loaded.

Two types of igniters were used for the closed bomb testing. One type was a bag igniter with 3.0 grains of double-base propellant and the other type was an S-94 (DuPont) squib.

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[9]Department of the Navy, Washington, D.C., NAVORDINST 8020.3, Explosives Hazard Classification Procedures, 19 May 1967.

*Registered trade mark of Rohm & Haas Co., Philadelphia, PA.

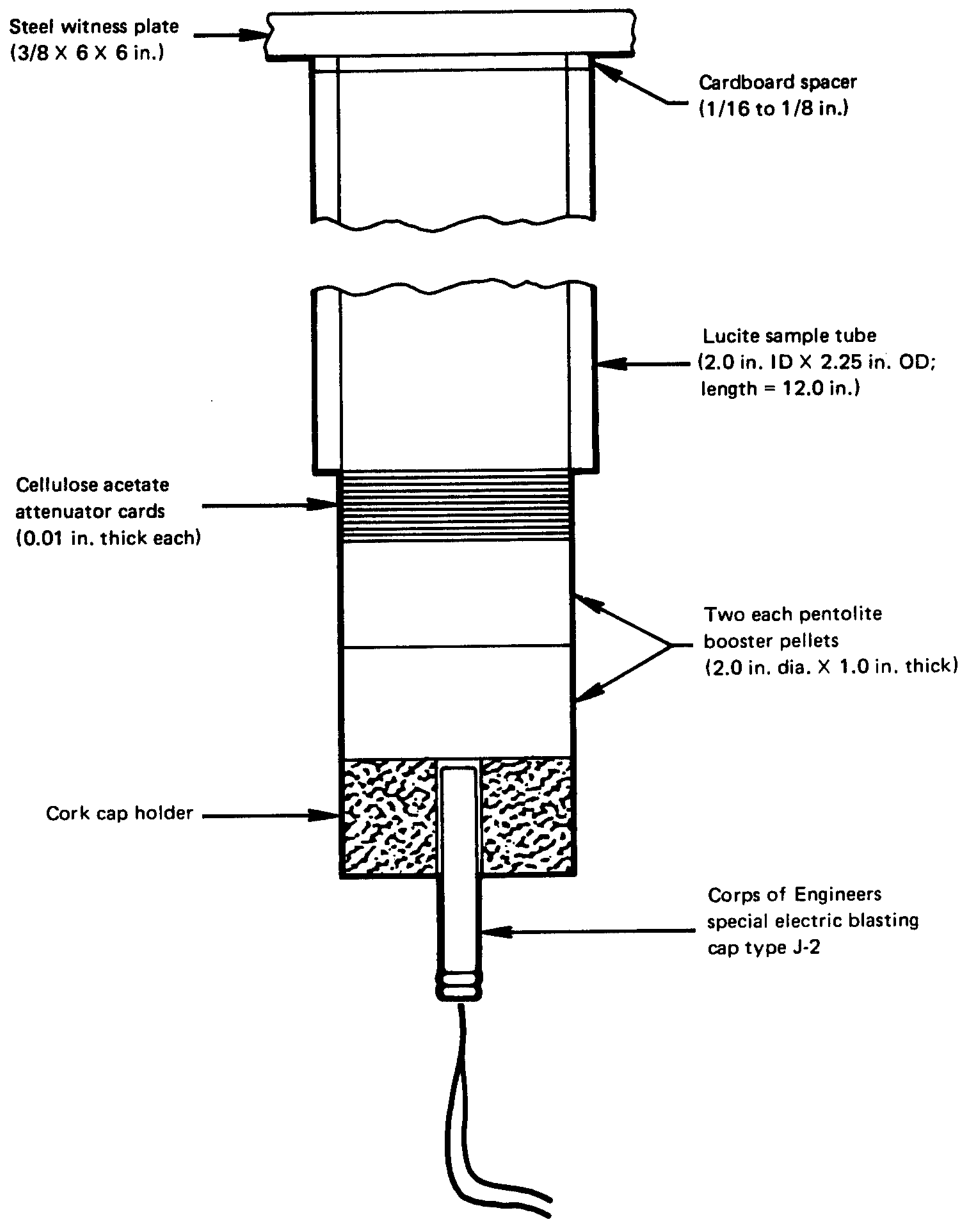

FIGURE 1. CARD GAP TEST SETUP

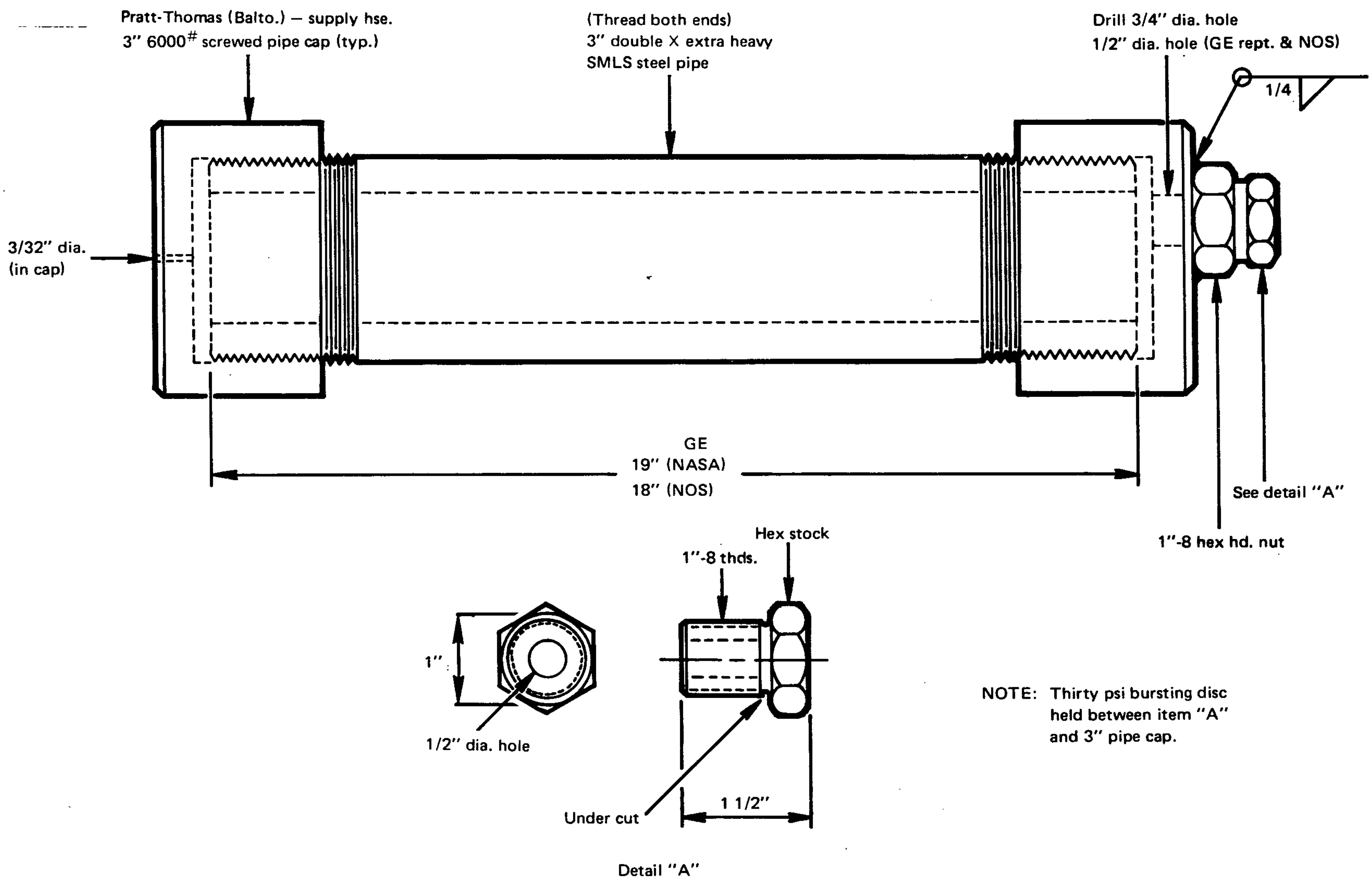

FIGURE 2. GE Input-Output Test: Construction Drawing

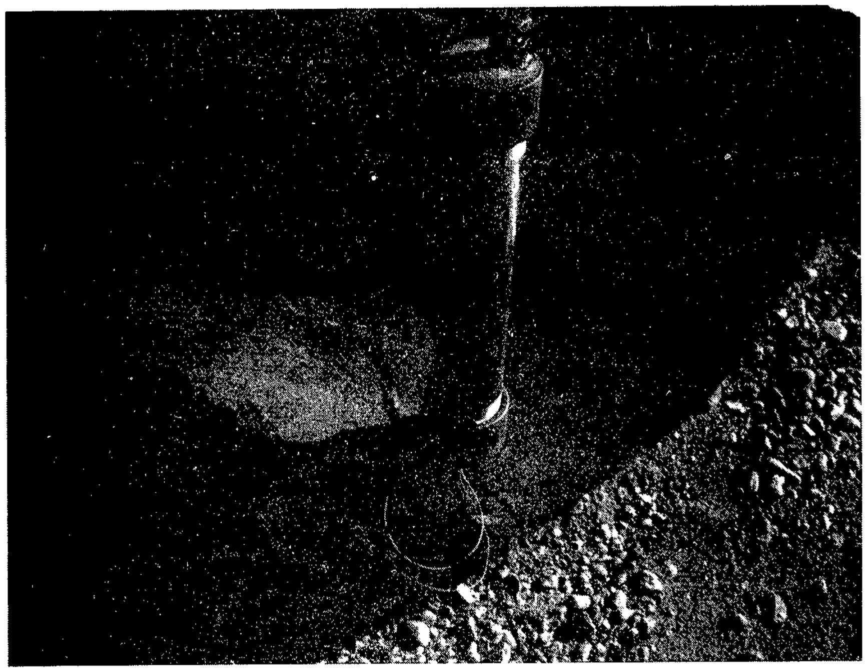

FIGURE 3. GE INPUT-OUTPUT TEST SETUP

Fragment Impact Test:

An important property of explosives is the response to fragment impact. In the past, it has often been assumed that the results from the bullet impact test can be taken as an indication of the behavior of explosives when impacted by fragments. It is now felt that separate fragment tests are needed. In the present series, small samples, about 0.3 pound of explosive, were loaded into cylindrical containers and placed in front of a steel back-up plate. The distance between the container and the back-up plate was varied from 1/8 inch to 12 inches in order to determine if there was an "anvil" efect. A general view of the equipment is shown in Figure 4. The standardized fragment consisted of a steel cylinder, 1/2 inch in diameter and 1/2 inch in length, with two chamfers on the end of the cylinder striking the explosive (Figure 5). The fragments weighed 208 grains and conformed to MIL-P-46593A. They were fired from a 0.50-caliber Mann barrel using 215 grains of DuPont IMR 4350 propellant. The average fragment velocity was 3600 ft/s measured at 50 feet from the muzzle. The cylindrical containers consisted of three types, as follows:

(1) Aluminum can, 1.75 inches in diameter, 2.5 inches in height, and closed with an aluminum cap; metal thickness was 0.018 inch.

(2) Cardboard cylinder, 2 inches in diameter, 2 inches in length with a wall thickness of 0.08 inch; the ends were closed with 1-1/2-inch-wide ordnance tape.

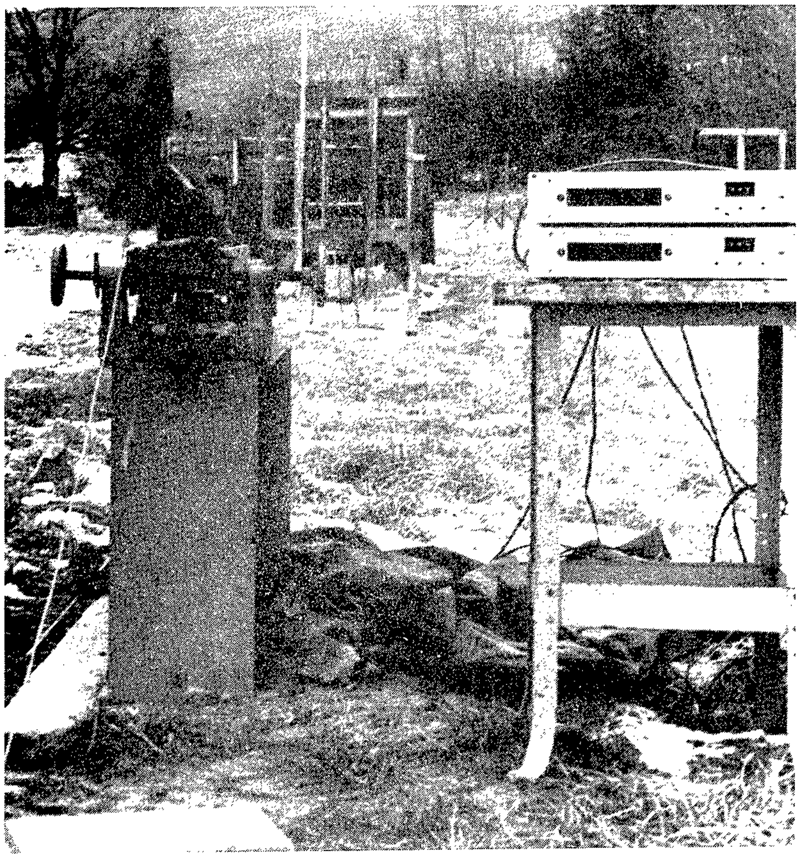

FIGURE 4. TEST SETUP FROM GUN POSITION

(3) Steel pipe, 1-1/2 inches in internal diameter, 3-1/2 inches in length, Sch 40 standard pipe; the ends were closed with 1-1/2-inch-wide ordnance tape.

In all cases, except when the steel pipe was used, the containers were in an upright position as shown in Figure 6. In the case of the steel pipe, the pipe was placed in a horizontal position and the fragment impacted the explosive along the cylindrical axis as shown in Figure 7. The result from a shot of GSX-2 in an aluminum container is shown in Figure 8.

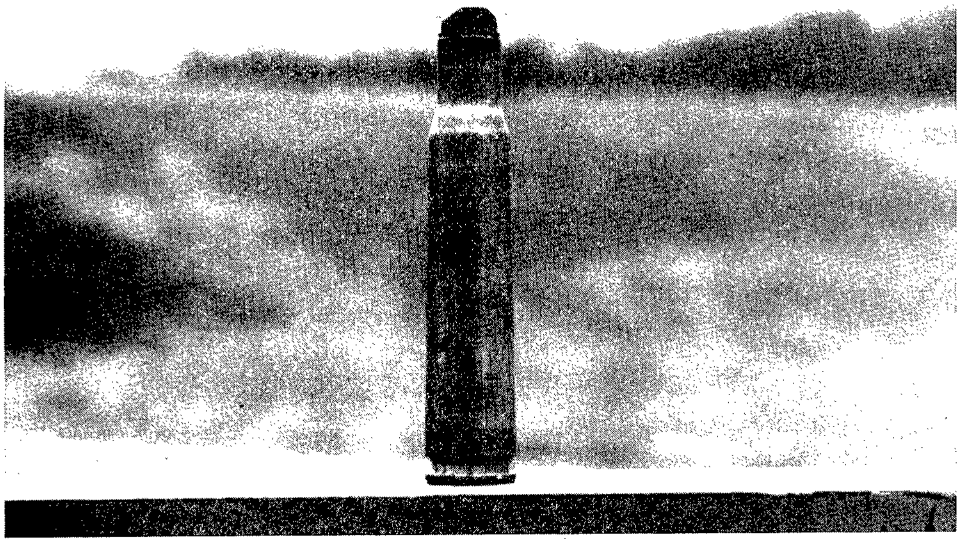

FIGURE 5. 0.50-CALIBER CARTRIDGE WITH FRAGMENT SIMULATOR PROJECTILE

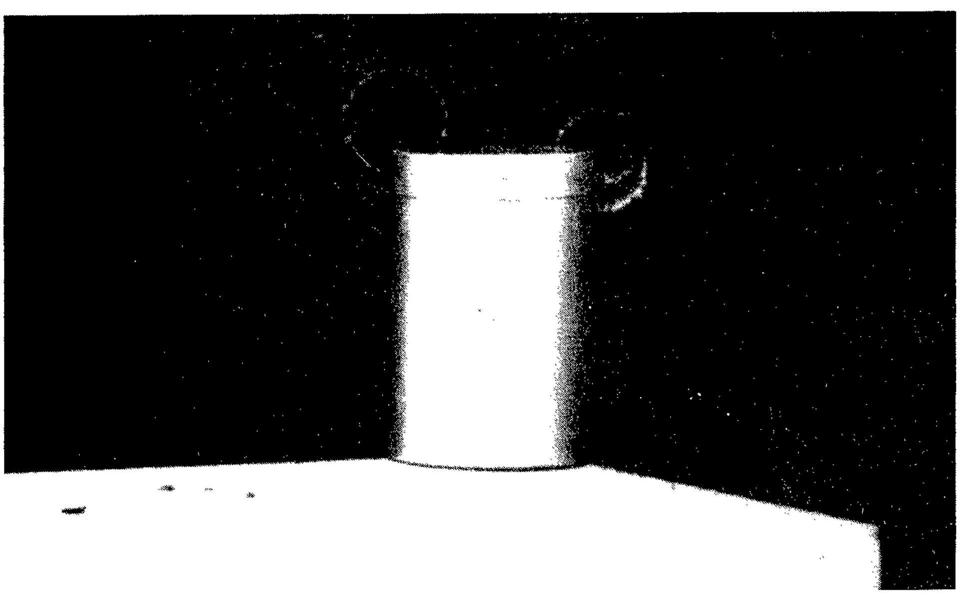

FIGURE 6. FRAGMENT IMPACT TEST SETUP–UPRIGHT POSITION

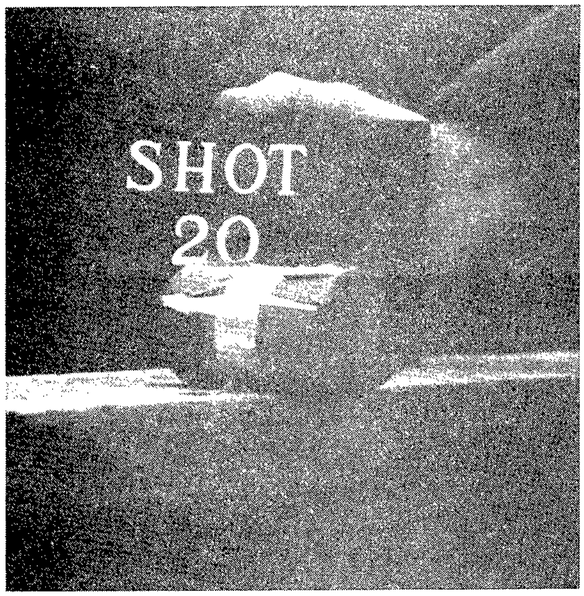

FIGURE 7. FRAGMENT IMPACT TEST–
HORIZONTAL POSITION

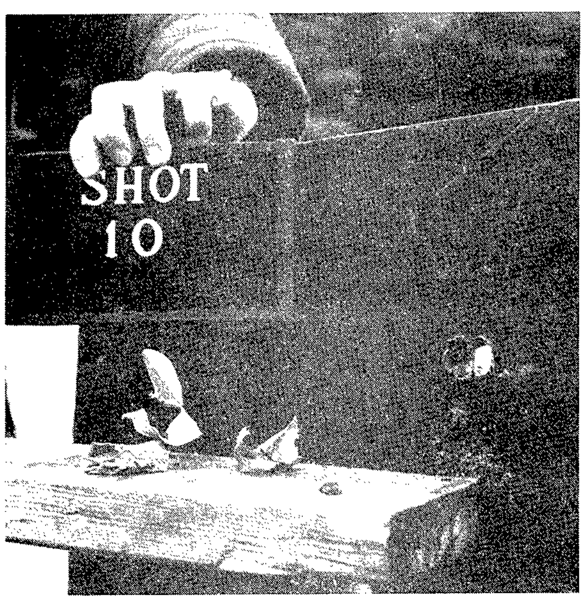

FIGURE 8. FRAGMENT IMPACT TEST RESULT
WITH GSX-2 IN ALUMINUM CONTAINER

DISCUSSION OF RESULTS

Card Gap Tests:

Sixteen tests were conducted with the four different GSX formulations to determine card gap sensitivity values. The results of those tests are shown in Table V. Since a value of 70 cards is the recommended point for differentiating between class A and class B explosives, no tests were conducted with more than 70 cards. GSX-1 (shots 6 through 9) showed positive results as indicated by the witness plate for values of 0, 40, and 70 cards. A more precise determination of its card gap sensitivity might be obtained if tests were conducted at more than 70 cards. However, this result may not occur if the detonation pressure of the slurry explosive is not great enough to penetrate cleanly through the steel plate. In a related manner, GSX-2 explosive (shots 1 through 5) showed the formation of bulged, as well as cracked, witness plates. While such a result is not counted as a positive, it nevertheless indicates a vigorous reaction which may be evidence of a steady state detonation. For GSX-4, shots 10 through 13, again bulged and cracked plates are reported which are counted as negative results but which may indicate a steady state detonation insufficient to penetrate the steel plate. Finally, for GSX-3 slurry, shots 14 through 16, there is no evidence of any explosive reaction.

TABLE V. CARD GAP TEST RESULTS

Shot No.	Explosive	No. of cards	Result	Comments
1	GSX-2	70	Neg	Bulged plate
2	GSX-2	40	Neg	Bulged plate
3	GSX-2	0	Neg	Bulged plate
4	GSX-2	0	Neg	Cracked plate
5	GSX-2	0	Neg	Cracked plate
6	GSX-1	0	Neg	Cracked plate
7	GSX-1	0	Pos	Cracked plate; slight hole
8	GSX-1	40	Pos	Cracked plate; slight hole
9	GSX-1	70	Pos	Cracked plate; slight hole
10[1]	GSX-4	70	Neg	Bulged plate; cracked
11[1]	GSX-4	40	Neg	Bulged plate; cracked
12[1]	GSX-4	0	Neg	Bulged plate; cracked
13	GSX-4	0	Neg	Bulged plate
14	GSX-3	70	Neg	Plate remained flat
15	GSX-3	0	Neg	Plate remained flat
16	GSX-3	0	Neg	Plate remained flat

[1]More than one bottom closure disc may have been used on the lucite sample column (i.e., 0.01-in thickness).

Input-Output Tests:

Twelve tests were conducted with GSX samples in the closed bomb. As shown by Table VI, the results were all negative; i.e., no rupture had occurred. After firing, the unreacted sample was removed from the bomb and examined. The electric match or squib fired as intended in all cases. Samples of GSX which are white showed that the pyrotechnic composition had burned while in contact with the explosive sample. Traces of combustion product from the pyrotechnic mix were seen where the ignition device was embedded in the sample. In no case was there any evidence that the GSX had ignited or produced any significant amount of gas.

TABLE VI. RESULTS OF CLOSED BOMB TESTS

[All samples packed in plastic sandwich bags.]

Shot No.	Sample	Sample weight (g)	Igniter	Results
1	GSX-1	100	M100[1]	No rupture
2	GSX-2	100	M100[1]	No rupture
3	GSX-3	100	M100[1]	No rupture
4	GSX-4	100	S-94	No rupture
5	GSX-1	100	S-94	No rupture
6	GSX-1	100	S-94	No rupture
7	GSX-2	100	S-94	No rupture
8	GSX-2	100	S-94	No rupture
9	GSX-3	100	S-94	No rupture
10	GSX-3	100	S-94	No rupture
11	GSX-4	100	S-94	No rupture
12	GSX-4	100	S-94	No rupture

[1]M100 electric match device was augmented by addition at 3.0 grains of double-base smokeless pistol powder in silk bag.

Fragment Impact Tests:

These test results are given in Table VII. GSX-1, GSX-2, and GSX-4 all reacted consistently with reactions ranging from violent to mild explosive reaction. The most reactive explosive is GSX-1. The least reactive is GSX-3 which did not seem to react at all. It seems to be reasonably certain that aluminum and steel containers contribute to the reactions of the GSX-1 and GSX-2 explosives. The reasons are different for the two different containers. For the aluminum, the probable mechanism is that the aluminum is heated by the impact; in turn, the explosive is initiated. In the steel container, where the explosive is initiated at the open end of the container, the heavy confinement appears to increase the explosive yield. When mild explosions were observed, there were often found quantities of unreacted explosive on the back-up plate.

TABLE VII. FRAGMENT IMPACT TESTS

[Backup Plate: 1/2-in-thick steel]

Shot No.	Sample	Container	Volume (in^3)	Plate separation distance (in)	Range (ft)	Results
1	GSX-1	Aluminum	5.30	0.12	75	Fragment grazed container; no reaction, all sample recovered; considered unfair test.
4	GSX-1	Aluminum	5.30	1.0	75	Mild explosion; aluminum container fragmented into small pieces; no traces of sample found.
9	GSX-1	Paper	6.28	0.12	30	Detonation with load report; all explosive consumed; explosion bulged backup plate.
10	GSX-2	Aluminum	5.30	1.0	30	Mild explosion with mild report; container torn open (large pieces).
11	GSX-2	Paper	6.28	1.0	30	Mild explosion with mild report; unreacted material splashed on backup plate.
12	GSX-3	Aluminum	5.30	1.0	30	Mild explosion with mild reports; container recovered in large pieces; unreacted material splashed on backup plate.
13	GSX-3	Paper	6.28	1.0	30	No reaction; sample scattered and splashed on backup plate.
14	GSX-4	Aluminum	5.30	1.0	30	Mild explosion with mild report; unreacted material splashed on plate.
15	GSX-4	Paper	6.28	1.0	30	Mild explosion with mild report; unreacted material splashed on plate.
16	GSX-1	Pipe	7.13	12.0	30	Detonation with loud report; pipe fragmented into small pieces; no unreacted material found.
17	GSX-1	Paper	6.28	1.0	30	Detonation with loud report; no unreacted material found.
18	GSX-2	Aluminum	5.30	0.12	30	Mild explosion with mild report; no unreacted material found.
19	GSX-2	Paper	6.28	0.12	30	Mild explosion with mild report; unreacted material splashed on plate.
20	GSX-2	Pipe	7.13	12.0	30	Fragment grazed pipe; no reaction; turned pipe around to fire shot 15.
21	GSX-2	Pipe	7.13	12.0	30	Moderate explosion; small amount of unreacted material found on backup plate; did not recover pipe or pipe fragments.

Differential Thermal Analysis Test Results:

Differential thermal analysis tests were run on four water gels, GSX-1 through GSX-4. The results for the water gels alone and when mixed with epoxy resin are shown in Figures 9 and 10. The exotherm begins between 150° and 180° C, indicating that more than the simple removal of water is taking place. Hence, it appears that no energetic residue remains.

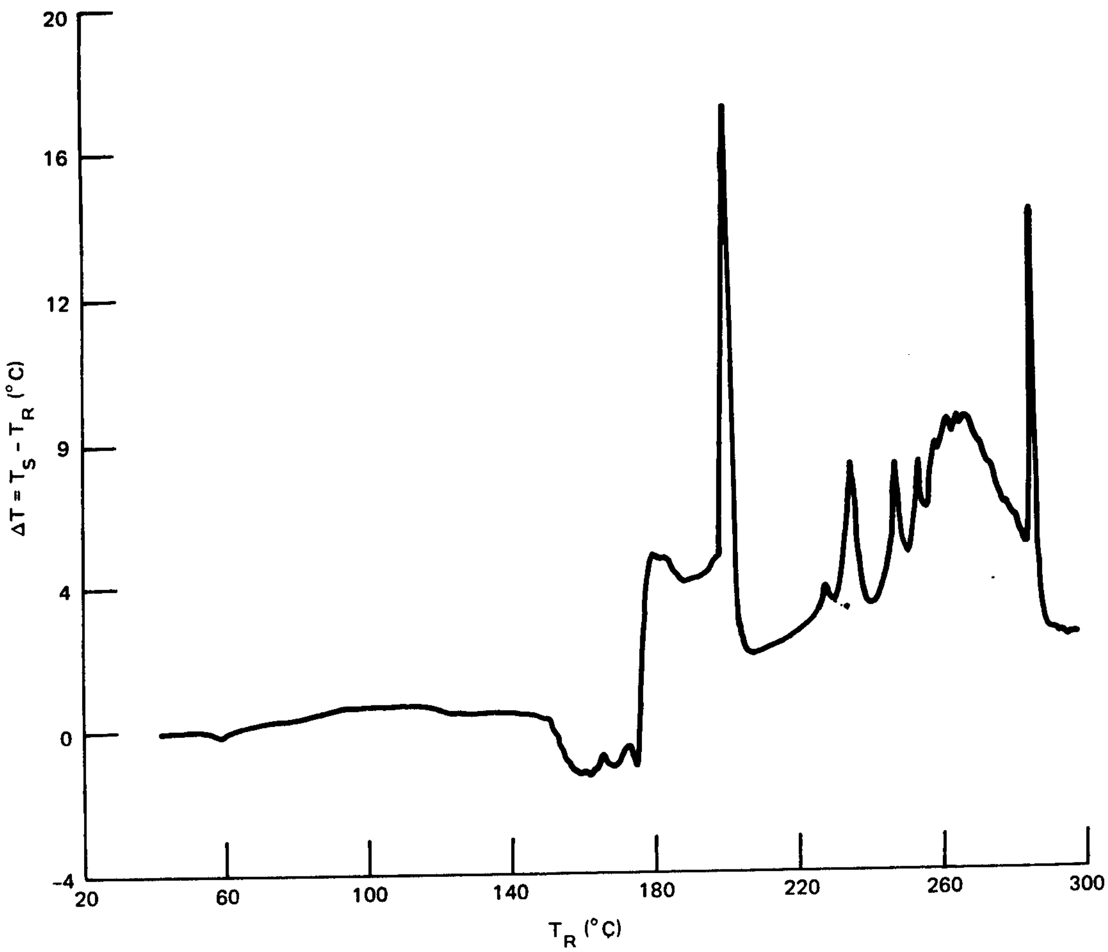

FIGURE 9. DIFFERENTIAL THERMAL ANALYSIS RESULTS OF GSX-3 ALONE

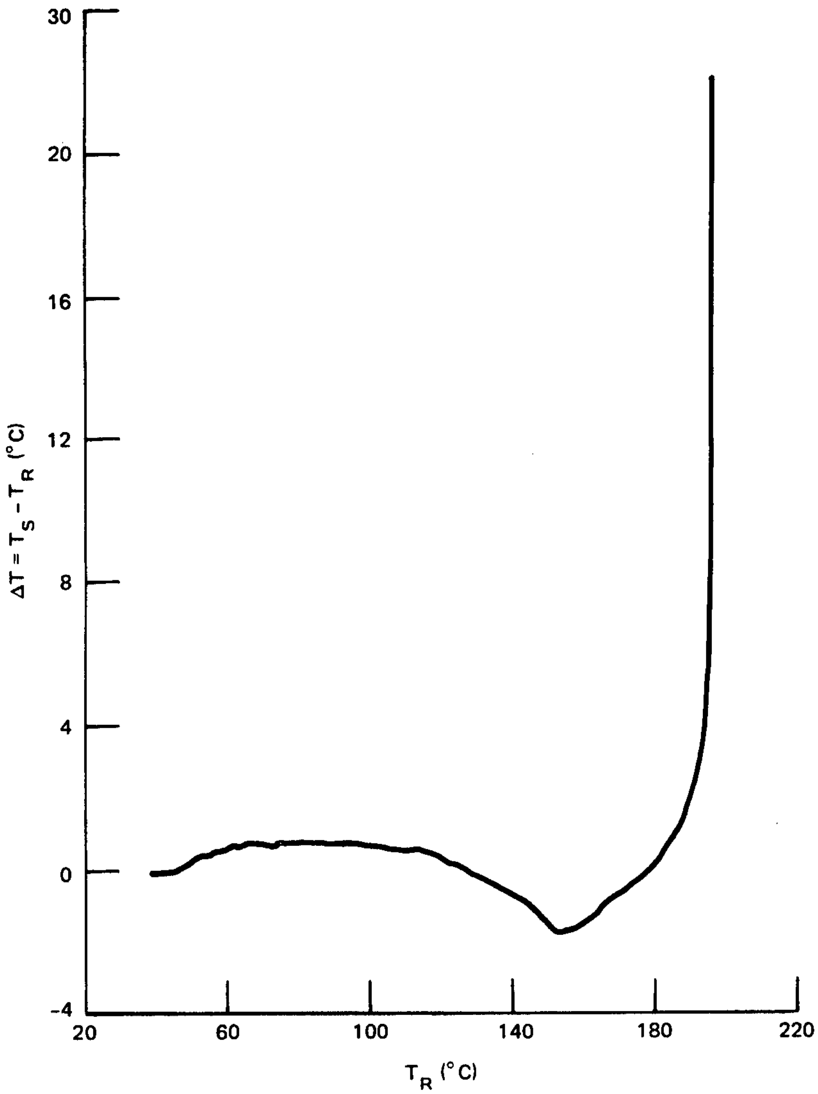

FIGURE 10. DIFFERENTIAL THERMAL ANALYSIS RESULTS OF GSX-3 AND EPOXY

EXPLOSIVE CLASSIFICATION

A review of the classification scheme recommended by DOT[10,11] indicates that it is generally acceptable. Some changes are desirable, however (Figure 11). The four divisions used by the United Nations are considered to form the proper basic framework. However, division 1.2 (GE class 2) needs to be subdivided into several groups corresponding to certain distance categories to which fragments are thrown. In addition, the definition for division 1.2 applies to explosives which do not explode en masse and which have a projection hazard but minor explosion effects. The interpretation of this definition would be that it refers to stacks of munition which usually explode sequentially. There is reason to believe that both the fragments and the so-called product cloud contribute to the sequential explosion process. Hence, the General Electric pressure vessel test[10] bears some relation to the second factor, but the range of conditions during the explosion is much more complex than is evident from the description of the test. At the present stage of knowledge on hazard classification systems, both the input-output test and the card gap test should be required to establish the distinction between division 1.3 explosives and minor hazards. It is also evident that water gels/blasting agents need to be placed in a new category of explosives. A major step in that direction has been recently taken by Department of Transportation in publishing Docket No. HM-143,[12] late in 1976. Among the comments submitted by the Naval Ordnance Station, Indian Head, was one that recommended the requirement of zero cards for blasting agents. Possibly, a requirement of less than 10 cards might also be acceptable. Recent information indicates that some of the ANFO's have card gap values up to 200 cards when a witness plate more sensitive than a 3/8-inch mild steel plate is used.

The relative merits of the card gap test, the blasting cap test, and the projectile impact test have been considered at some length for application to the blasting agents. In the case of the card gap test, the heavy confinement caused by the steel cylinder appears to have increased dramatically the sensitivity of the explosive. The full significance of these results is not understood at this time. Possibly a reevaluation of the type of confinement as well as a change in the diameter of the acceptor needs to be studied. The drastic increase in card gap sensitivity has not been accompanied by an increase in cap sensitivity. The conditions for the cap test are also subject to reevaluation such as the size of the acceptor, the diameter of the acceptor, the type of cap, and whether the cap is imbedded in or is flush with the surface of the acceptor.

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[10] Department of Transportation, Washington, D.C. 20590, Hazard Classification of Explosives for Transportation, Evaluation of Test Methods, Phase I, by P. V. King and A. H. Lasseigne, Contractor report TSA-20-72-5 (NTIS PB 223769/AS), May 1972.

[11] Department of Transportation, Washington, D.C. 20590, Hazard Classification of Explosives for Transportation, Evaluation of Test Methods, Phase II, by A. H. Lasseigne, Contractor report TSA-20-73-2 (NTIS PB 225122/5AS), May 1973.

[12] Department of Transportation, Washington, D.C. 20590, DOT Notice 76-11, "Blasting Agents," Federal Register Vol 41, No. 229, 26 November 1976.

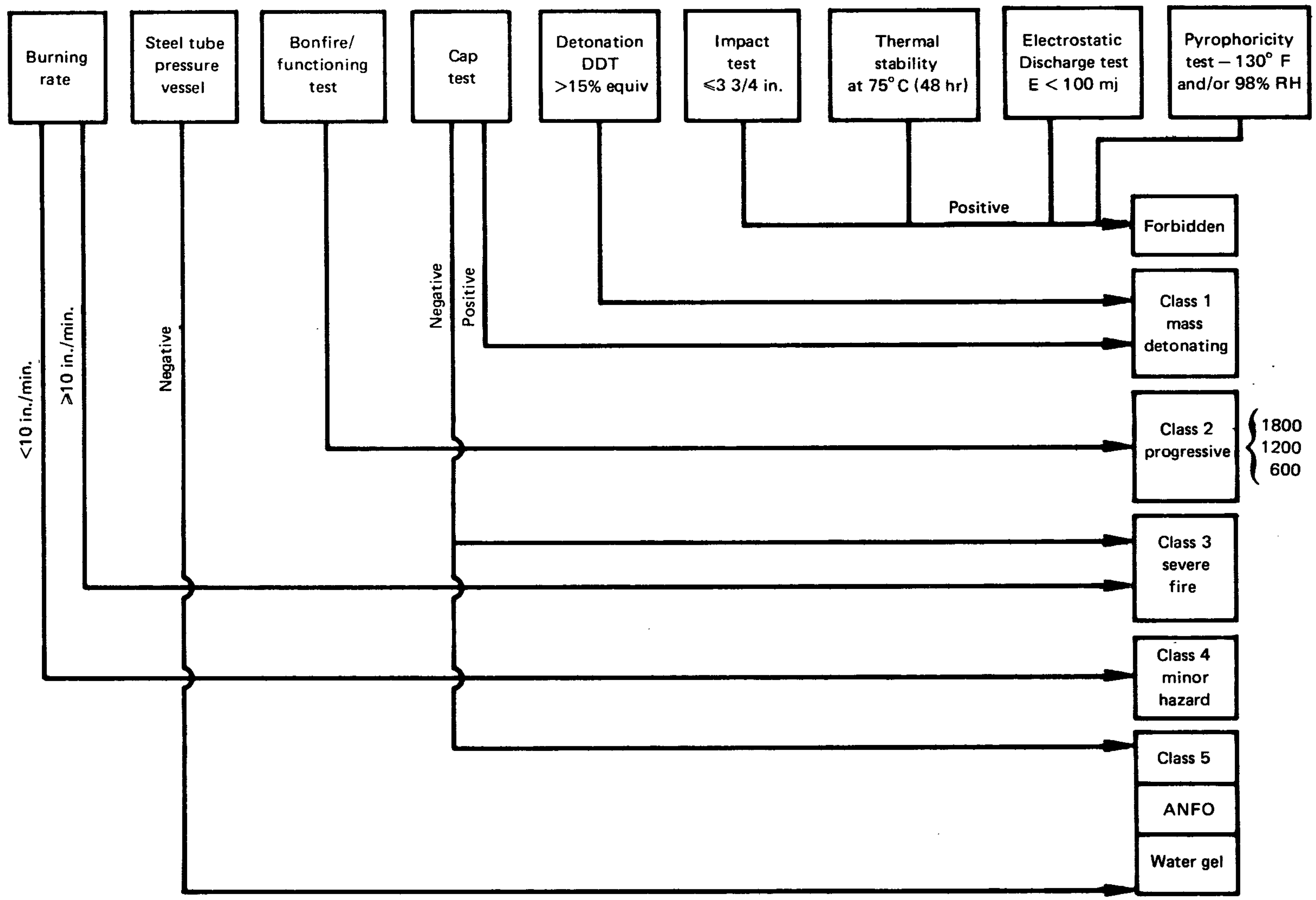

FIGURE 11. PROPOSED EXPLOSIVE CLASSIFICATION SCHEME

Complications also exist with the projectile impact test. Here again it is suspected that the diameter of the cylindrical projectile and the size and condition of the sample are important factors in changing the ranking of explosives. A more detailed discussion of these factors for the card gap test, the cap test, and the projectile impact tests is planned for a subsequent report. Because of these uncertainties it is concluded that, on an interim basis, the cap test be accepted as being historically the most acceptable test. In addition to the above three tests, consideration must be given to the deflagration-to-detonation test as it represents a hazard condition that is believed to exist under a variety of storage and transportation situations.

CONCLUSIONS

(1) Reactions with water gels were obtained in all card gap tests and fragment impact tests except for GSX-3 in the card gap test.

(2) The input-output test as presently performed was not really applicable because of the large amount of water in the water gels.

(3) No relationship has been established between the input-output test and conditions which exist when stacks of explosives react sequentially (i.e., for explosives not reacting en masse).

(4) Temperature can have an important effect in increasing the sensitivity of liquid monopropellants.

(5) Ambiguity exists in the interpretation of adiabatic compression results for monopropellants because the effects of heat transfer, reaction time, and impacting of droplets are not well understood at this time.

(6) Some relative ranking is needed for nonsolid explosives (i.e., to be related by both the card gap test and some form of the flying plate or fragment impact test).

(7) To assess the detonation hazard caused by shipping stacks of blasting agents, the deflagration-to-detonation test is needed. The most acceptable tests at the present time for division 1.2 are the ammunition stack tests. Two types of tests are needed: bonfire and initiating one unit in a stack by its normal method of initiation.

(8) The Hazards Classification System proposed by General Electric Co. should be modified to reinterpret the input-output test. The reinterpretation should include a comparison with other closed bomb tests and a better understanding of the output feature of the test.

(9) The cap test is considered acceptable at the present time to identify a class A explosive when the test is positive. For a water gel or ANFO, if the result is negative, the cap test is considered acceptable for identifying the material as blasting agent, class 5 (UN division 1.5).

RECOMMENDATIONS

(1) A long range approach to adiabatic compression interpretation is needed.

(2) A test program for ammonium nitrate fuel oil explosives should be set up; in particular, the card gap, flying plate, and deflagration-to-detonation tests are recommended.

(3) It is desirable to investigate modifications of the card gap test; i.e., larger diameters, such as 2 inches, and use of plastic tubing instead of steel in order to simplify the design of protective walls. The protective walls can be made of wood instead of steel if plastic tubing is substituted for steel.